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FINAL REPORT

BIOSATELLITE EXPERIMENT P-1059 "DYNAMIC MONITOR OF THE CARDIOVASCULAR SYSTEM IN WEIGHTLESSNESS"

CONTRACT NAS 2-1535

PREPARED FOR

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SR64-1012
AUGUST 31, 1964

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1.0 System Description

1.1 Design Rationale

The Pulse Wave Velocity Computer is designed to compute the ratio

$$PWV = L/I \text{ (m/sec)}$$

where: PWV is defined as arterial pulse wave velocity,

L equals the arterial length selected for measurement, and

I equals the pulse transit time over the arterial length L.

The computer calculates a PWV value for each pressure pulse produced by the heart, and provides a step-wise analog output signal proportional to the continuous PWV function. The arterial length L will frequently be taken as the length from the heart to some point on the peripheral circulation. In that case, the transit time I represents the time elapsed between the expulsion of blood by the heart and detection of the resulting pulse by a peripheral transducer. It is possible to detect the mechanical contraction of the heart by various sensing means. It is simpler and more reliable, however, to use the electrocardiographic (ECG) signal, which preceeds mechanical contraction by about 40 ms, as an indication of blood expulsion. If this is done, the measured transit time must be corrected for the estimated electromechanical delay (EMD), so that

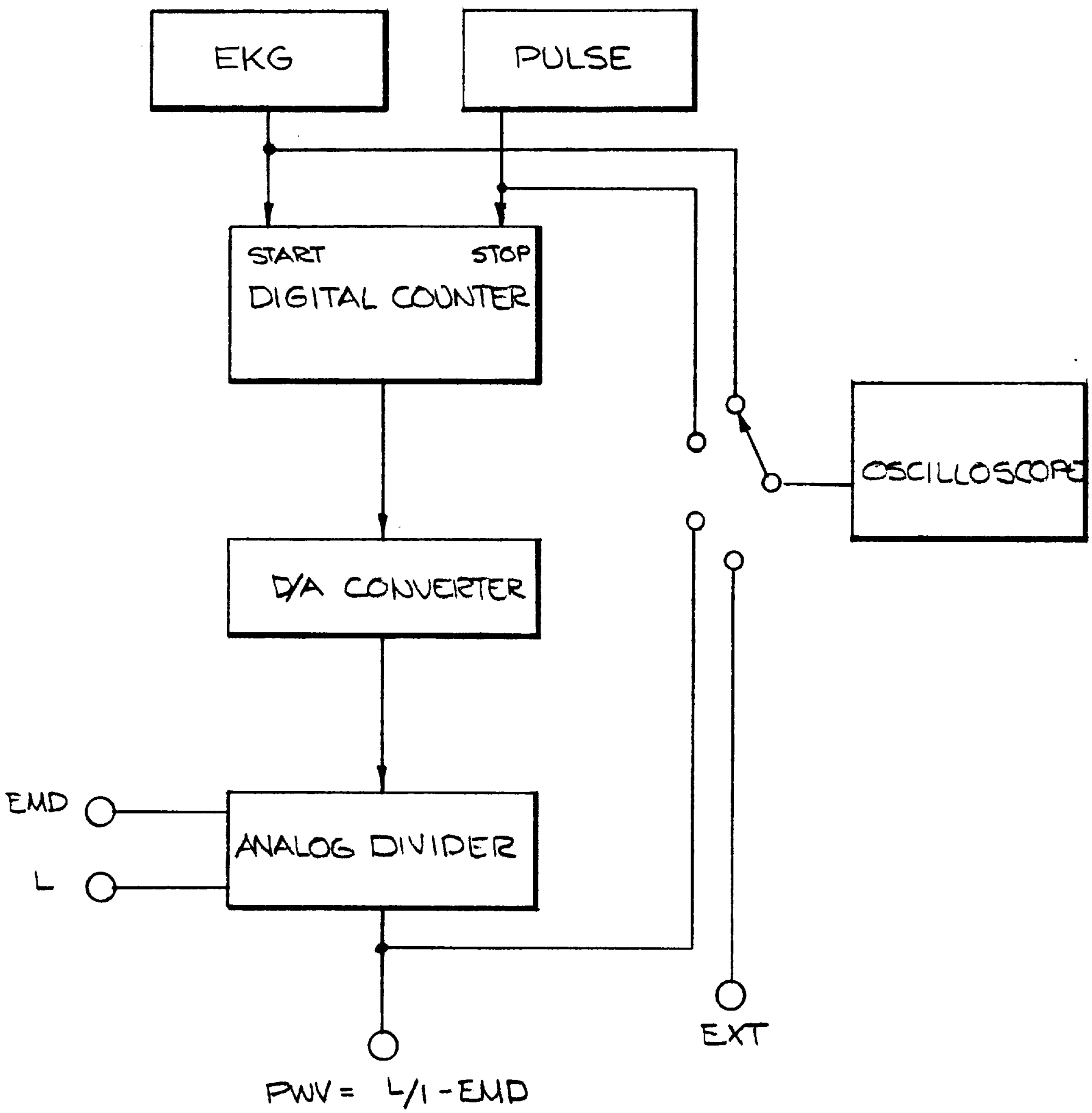
$$PWV = \frac{L}{I\text{-}EMD} \text{ (m/sec)}$$

There are several ways to compute continuously the arterial PWV. All analog methods, however, can only approximate the reciprocal function involved, and so their accuracy is inherently limited. The present Pulse Wave Velocity Computer is conceived of as a laboratory test apparatus, for which repeatability is the prime criterion, rather than as a piece of commercial equipment, for which expediency occupies the same role. Accordingly, a digital time-measuring technique is combined with an analog dividing network, and the integral system elements functionally separated so that they can be individually checked and calibrated. Proven commercial subassemblies are used wherever possible to ensure the maximum degree of reliability, accuracy, and precision.

This design approach provides a substantial amount of flexibility in system operation, so that the computer can be readily adapted to any unexpected experimental development. For example, various physiological transducers can be connected to the preamplifiers provided, and some filtering or triggering operations might even preceed the computer inputs now used. The digital result of the time measurement is available as an output if it is desired to compute the PWV by more accurate means while using the present computer output as an analog monitor. Internal calibration factors can be adjusted to compensate for unwieldy PWV values and the calibrated PWV output can be applied to various permanent recorders while being observed on the computer oscilloscope. Additional units, such as a heart rate monitor, can be easily added to the present computer configuration.

1.2 System Configuration

Figure 1 presents a photograph of the spacelabs' Pulse Wave Velocity Computer, and identifies its functional elements. Figure 2 illustrates schematically how these elements are interconnected. ECG and PULSE preamplifiers provide amplified sensor inputs to the Digital Counter. For each heartbeat the ECG signal starts the count, and the Pulse signal



PWV COMPUTER BASIC SCHEMATIC DIAGRAM

FIG 2

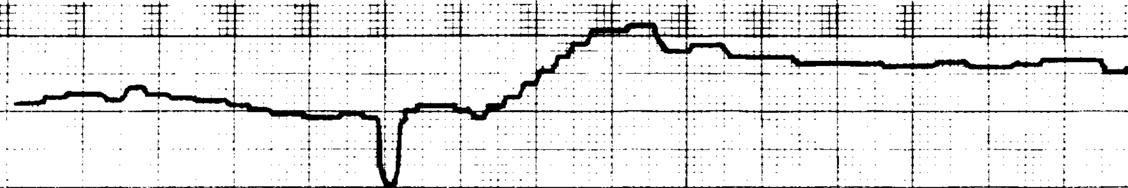
stops it. The resulting digital quantity is transformed to a proportional analog voltage by the D/A converter. The D/A converter stores each transit time value until a new one is received, and therefore generates a continuous step-wise analog output. This continuous analog voltage is combined with preset L and EMD voltages in the analog divider to produce a continuous output voltage proportional to PWV. During operation, the oscilloscope can be used to monitor the incoming EKG or Pulse waveforms, the outgoing PWV level, or an arbitrary external voltage. (A complete wiring diagram of the PWV computer is presented in Appendix A.) Figure 3 shows a portion of a subject's PWV record transcribed on a Sanborn Recorder. The marked rise in PWV occurred after prolonged breathholding. The preceeding short, sudden drop is most likely a sensor artifact. The record illustrates the step-wise character of the PWV function.

1.3 System Components

Complete Instruction Manuals for all of the commercial units incorporated into the PWV computer are appended to this report. The following short descriptions are intended to prepare the reader for the subsequent section on system operation.

1.3.1 Preamplifiers

A ten-foot cable links the PWV computer to the EKG and Pulse preamplifiers. Both of these are subminiature, solid-state units and combine high input impedance and wide frequency response with good temperature stability.



EXAMPLE OF PWV OUTPUT RECORD

FIGURE 3

EKG Preamplifier - The specifications of this unit are presented in Appendix B. It provides a three-lead differential input for standard EKG signal detection, an input resistance of 2 megohms differential, and a gain of about 1000. Its frequency range extends from 0.2 cps to approximately 110 cps.

Pulse Preamplifier

This unit provides a single-ended input, an input resistance of 3.3 megohms, and a gain adjustable from 0.5 to 13. The frequency range has been left wide (from 2.5 cps to 300 kcps) to permit the utilization of a wide variety of input transducers.

The preamplifiers are connected together with a short length of cable. They may be secured on the test subject, or placed in proximity in a more permanent enclosure. It is good practice to minimize the lead length between subject and preamplifier.

1.3.2 Electronic Counter

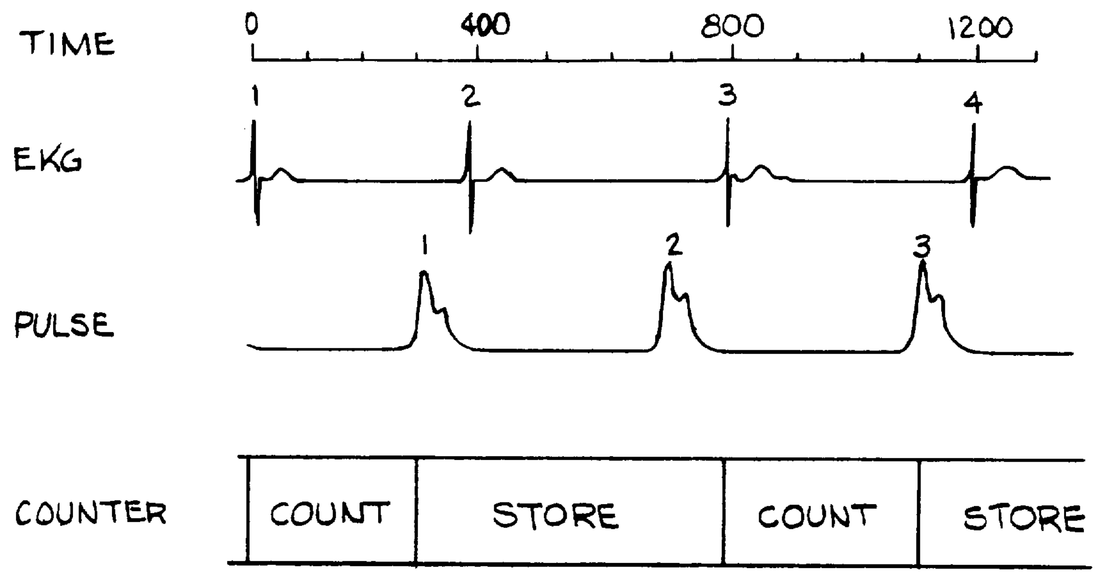
A Hewlett-Packard Model 5233L Electronic Counter is used. Its Instruction Manual is found in Appendix C. The counter is operated in the Time Interval Mode. The amplified EKG signal provides the A (start) input; the Pulse signal provides the B (stop) input. Normally, the counter will be set to trigger on the rising slope of the "R" wave; but alternative points can be selected. With the Time Base/Multiplier Selector switch in the 1 ms x 10^3 position, the far-right digits of the counter display record in milliseconds the time between the appearance of the R wave spike and detection of the peripheral pulse. This time interval will be about 200-300 ms for resting human subjects when the pulse sensor is placed on the wrist. The output of the counter is a set of Binary Coded Decimal (BCD) signals representing the transit time interval.

The minimum display time of this counter is 200 msec. Thus there is an unavoidable 200 msec delay between the time that a peripheral pulse is received and the time that an EKG signal can initiate a new cycle. This means that for a heart rate of HR beats/min, the transit time interval cannot exceed

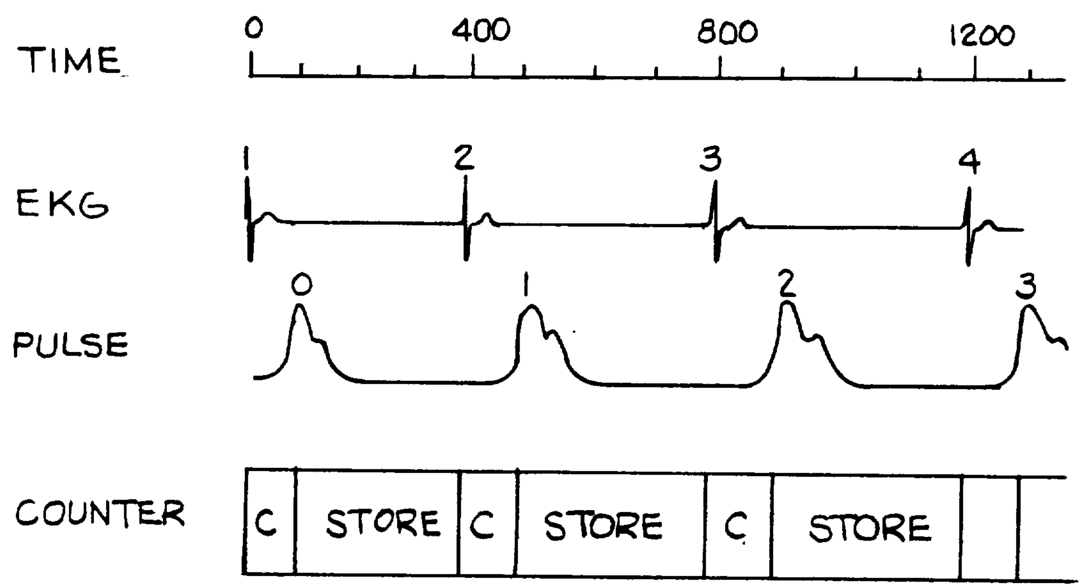
$$I_{max} = \frac{6 \times 10^4}{HR} - 200 \quad (\text{msec})$$

if every individual PWV value is to be recorded. For a somewhat elevated human heart rate of 150 beats/min, I_{max} would be 200 msec. This appears reasonable for the heart-wrist distance, since PWV would probably rise somewhat with heart rate, but it may be too low for a heart-to-foot arterial length. Suppose that for HR = 150 beats/min, I = 300 msec. The computing situation would be as pictured in Figure 4a, the counter would compute every second I value, and would store this number during the intervals it had missed at its start signal. The PWV output would remain accurate and continuous. At high heart rates, the halving of data points would not be important.

If, however, the heart rate and transit time relationship is such



4a. A SITUATION IN WHICH $\frac{6 \times 10^4}{HR} - 200 < I < \frac{6 \times 10^4}{HR}$



4b. A SITUATION IN WHICH $I > \frac{6 \times 10^4}{HR}$

TIMING RELATIONS FOR TWO PWV SITUATIONS

FIGURE 4

that

$$I\,(\mathrm{msec}) > \frac{6 \times 10^4}{HR}$$

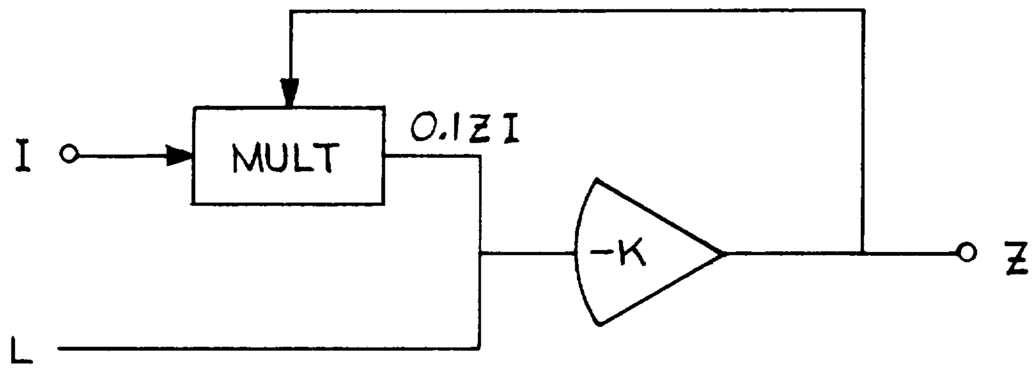
then this simple compensation will not occur. Such a situation, diagrammed in Figure 4b, would produce erroneously low I values because of the phase change in the EKG and Pulse signals. A count cycle initiated by the nth EKG complex would be terminated by the (n-1)th peripheral pulse signal. It would probably be necessary to introduce some prior logic circuitry to resolve this situation. Such logic would then necessarily again halve the available data points.

1.3.3 Digital/Analog Converter

The BCD output of the Electronic Counter is converted to an analog voltage level by a Hewlett-Packard Model 580A Digital/ Analog Converter (Appendix D). This unit operates on any three consecutive digits of the decimal count. Normally it is set to convert the three far-right digits. The analog output voltage is obtained by feeding the D/A Converter's Galvanometer Recorder output current into a grounded 1 k resistor. A zero count produces zero voltage. A count of 999, representing 999 msc, produces a voltage of 1.0 volts. Thus the scale factor at this point is 1 v/sec. The A/D converter holds its output level until a new count is received. Thus there is no reset discontinuity between heartbeats and the converter output is an accurate analog representation of the pulse transit time function.

1.4 Analog Divider

The analog divider is formed by placing a multiplier in the feedback loop of an operational amplifier. Figure 5 illustrates the technique. The circuit operates in the following manner.



AN ANALOG DIVIDER CIRCUIT

FIGURE 5

The output Z can be expressed

$$Z = -K(0.1\,Z\,I + L)$$

rearranging terms and dividing by 0.1 I

$$KZ + \frac{10Z}{I} = -10\,\frac{KL}{I}$$

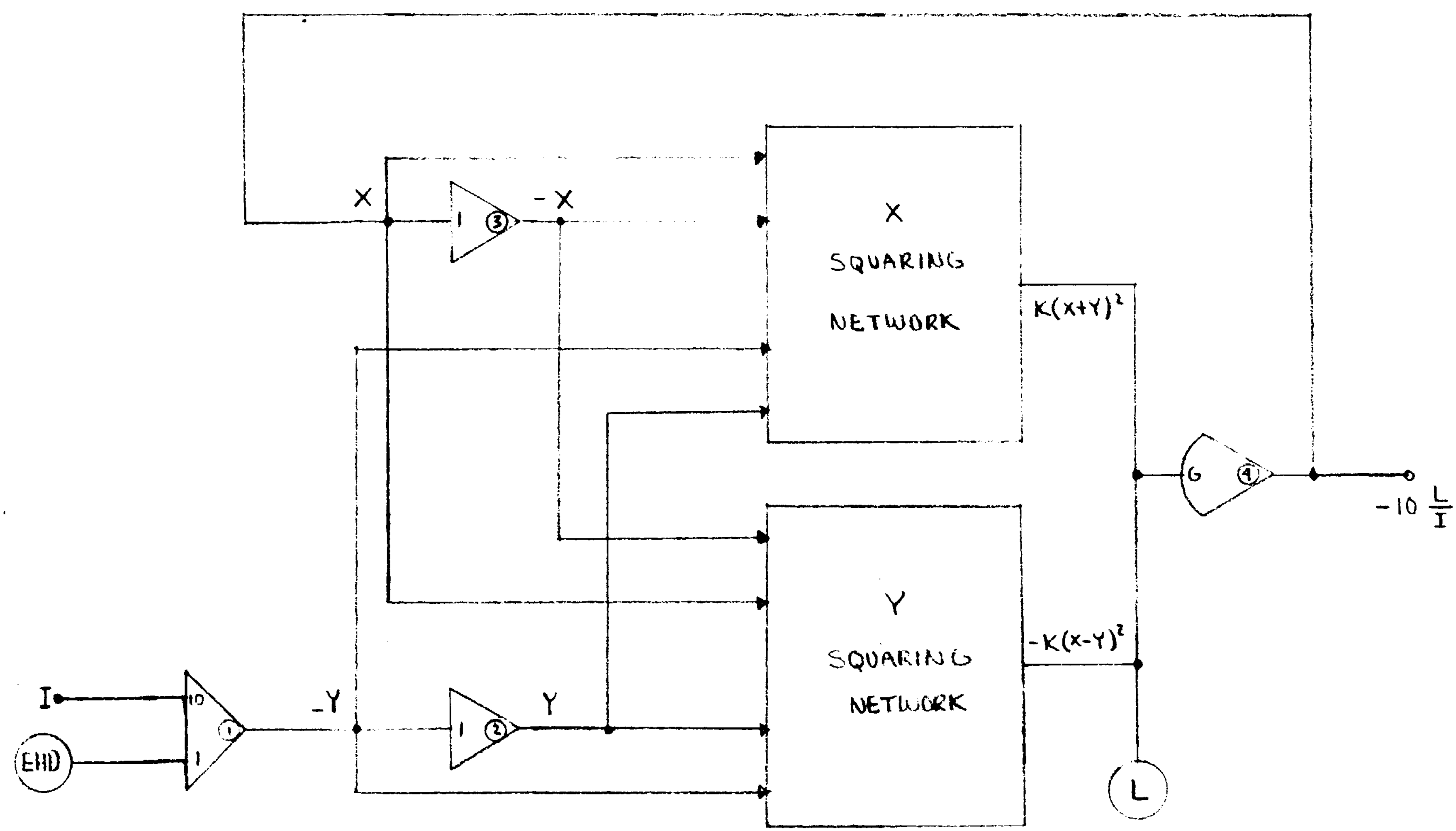
so that

$$Z\left(1 + \frac{10}{K(I)}\right) = -10\frac{L}{I}$$

and for K very large

$$Z = -10\frac{L}{I}$$

Figure 6 shows the circuit as actually fabricated using Donnor Model 3811 Transistor Operation Amplifiers, a Donnor Model 3732 Quarter-Square Electronic Multiplier, and a Donnor Model 3805 Power Supply (Appendix E).



ANALOG DIVIDER SCHEMATIC DIAGRAM

FIGURE 6

The incoming I signal from the A/D Converter appears with a gain of 10 at the same time that it is summed with a variable negative voltage scaled to represent a 0 to 60 msec EMD. The resultant voltage forms the Y input to the dual squaring networks. The final output forms the X input, and inverting amplifiers provide the required -Y and -X signals. Diode function generators are used for both squaring networks. They form the product XY by the electrical simulation of the alebraic expression

$$\left(\frac{X + Y}{2}\right)^2 - \left(\frac{X - Y}{2}\right)^2 = XY$$

A variable voltage L proportional to the arterial length in meters (scale factor 1 V/m) is summed with the product at the input to the final operational amplifier. The output voltage is proportional to PWV, and is scaled so that 1 V equals 1 meter/sec. It remains stable as long as the absolute value of Y remains greater than the absolute value of L. This means, for example, that for L equal to 1 meter, I - EMD must be greater than 100 msec. The PWV output is thus effectively limited to 10 meter/sec with the scaling outlined above; beyond this, accuracy decreases markedly.

The scaling can be changed for special situations. Assume sensors are placed at two points along the arterial circulation path. Let us say L = 0.225 meters, and I = 15 msec, so that PWV = 15 meter/sec, which is outside the computer range. However, if the Time Base Multiplier switch of the Digital Counter is changed to the 0.1 ms x 10^2 position, the last three Counter digits will read 15.0 instead of 015. The A/D converter output voltage is thus increased by a factor of ten, and the ratio L / Y becomes less than one. A compensating change is made in the Analog Divider output scale factor, so that the output voltage of 1.5 V is interpreted as 15 m/sec rather than 1.5 m/sec.

The Analog Divider unit is by far the least accurate component of the PWV computer system. This is because the quotient formed is inherently an approximation. The squaring networks themselves contain inaccuracies, and the manufacturer's performance ratings for their 100 V units seem to be degraded severely for the solid-state 10 V modification. As previously mentioned, analog division is always a problem, and the superfine equipment used to ensure accuracy in large-scale computing applications is prohibitively expensive for data processing. However, it appears that with careful calibration, overall system accuracy from counter reading to PWV output can be kept within 3% of full scale. If the implied 0.3 meter/sec uncertainty in recorded PWV is unacceptable, data may be corrected by the use of calibration curves. The PWV computer is relatively stable, and thus the calibration curves are repeatable even where non-linear.

1.5 Monitoring Oscilloscope

A Hewlett-Packard Model 120B Oscilloscope is incorporated as a monitoring unit in the PWV Computer System. In normal operation, the oscilloscope is used to examine the EKG and peripheral pulse signals after preamplification, and to observe the current PWV level without the necessity of reading a supplementary strip chart record. Provision is included for monitoring one additional External signal during a PWV run. The oscilloscope is also employed during pre-run setup and calibration, replacing a voltmeter in this case. Complete operating instructions for this unit are provided in Appendix F.

2.0 System Operation

2.1 General

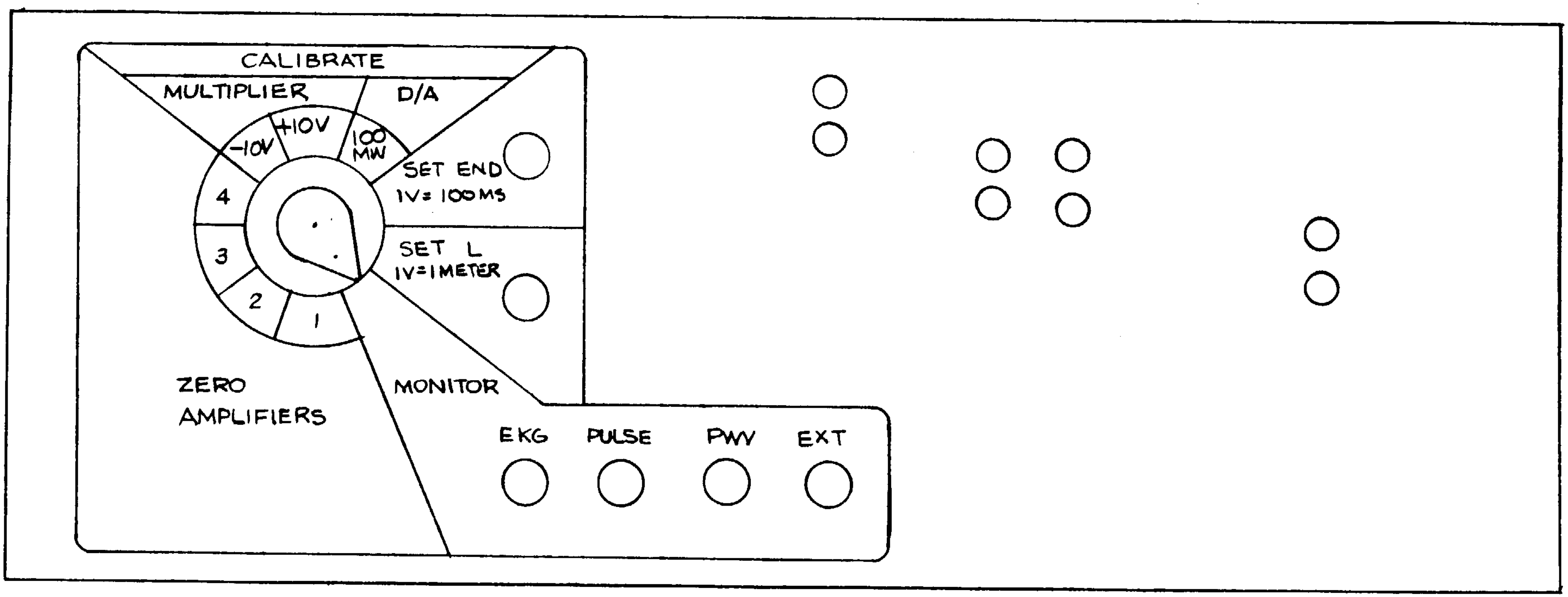
Setup and operation of the PWV Computer centers about the control panel incorporated onto the Analog Divider chassis. The control panel, pictured in Figure 7, permits the various components to be calibrated and adjusted in a straight forward manner. It simplifies and speeds the system check which should preceed every test run. It accomplishes this by use of a main rotary switch which sequentially places the proper component output on the oscilloscope face.

2.2 Operating Instructions

2.2.1 Power

The PWV computer is equipped with a detachable three-wire power cable. The cable socket mates with the recessed plug on the right side of the computer cabinet. The three-prong plug is connected to a 115 volt a.c. grounded power outlet. Grounding should be accomplished through a connector adapter when only a two-blade outlet is available.

Power is supplied to all of the component units through the main power switch located directly below the slide-out drawer. All of the individual units are normally left in an "on" condition.



THE PWV COMPUTER CONTROL PANEL

FIGURE 7

Some of the units, particularly the analog divider, have an appreciable warmup delay. Because of this, a wait of at least 30 minutes should follow initial turn-on.

2.2.2 Oscilloscope

Only the vertical amplifier section of this unit is normally of interest. Its calibration is checked by setting the Sensitivity Switch to CAL and adjusting the associated CAL potentiometer with a screwdriver to produce a 6 cm peak-to-peak square-wave voltage on the oscilloscope face.

Note: The PWV Computer Oscilloscope is not completely accurate as a voltage measuring device when used over its full 10 cm beam deflection range, as recommended in several of the following procedures. If greater setting accuracy is desired it is possible to adopt one of two alternatives:

a. Halve the sensitivity of the vertical amplifier by setting the VERTICAL VERNIER knob to produce a 3 cm rather than a 6 cm deflection for the internal calibration voltage. This will permit full-scale measurements to be confined to the center of the oscilloscope display, but will necessitate a re-evaluation of all scale factors.

b. Parallel the oscilloscope input terminals with an accurate, multi-scale VTVM, and use voltage scale factors instead of deflection calibration. The VTVM can be comfortably placed on the slide-out shelf during the calibration procedure.

The use of a separate voltage meter is preferable to oscilloscope recalibration, and is strongly recommended.

2.2.3 Counter

With the Electronic Counter in its operating mode, that is

Function	=	Time Interval A-B
Time Base-Multiplier	=	10^3 x 1 ms
Sample Rate	=	Far Counterclockwise

set the input select switch to CHECK, making certain that both input Slope toggle switches are set to the same slope direction. The counter should then display 1000 ms. Set the input select switch back to SEP. No provision is made for adjustment of the internal frequency standard, so that if any discrepancy occurs, the local Hewlett-Packard representative should be contacted.

2.2.4 Zero Amplifiers

This procedure sets the zero level of the operational amplifiers used in the Analog Divider. The amplifier outputs are checked with the inputs grounded.

(a) On the oscilloscope:

(1) Establish a zero reference in the center of the oscilloscope screen. (This can be done by moving the Vertical Sensitivity Switch to OFF, and centering the trace with vertical POSITION knob; or it may be more quickly accomplished

at any sensitivity setting by flicking the a. c. - d. c. input switch to a. c., positioning the trace, and then moving it back to d. c.).

(2) Set the sweep to about 2 ms/cm.

(3) Set vertical sensitivity to 10 mv/cm.

(b) On the PWV Computer Control Panel:

(1) Set the central rotary switch to ZERO AMPLIFIERS/1.

(2) Zero the d. c. level of the first amplifier by setting the potentiometer behind the AMP 1 hole with a fine screwdriver. Disregard the high frequency noise on the signal, and null only the d. c. offset.

(3) Repeat steps b. 1. and b. 2. for amplifiers 2, 3, and 4.

2.2.5 Calibrate Multiplier

This procedure adjusts the gain of the X and Y squaring networks on the multiplier card of the Analog Divider. Standard voltages of X = Y - 10 v and X = 10 v and Y = 10 v are inserted in place of the normal X and Y voltages.

(a) On the Oscilloscope:

(1) Set vertical sensitivity to 1 v/cm.

(2) Establish a zero on the top marking of the screen relicle.

(b) On the PWV Computer Control Panel:

(1) Set the central rotary switch to CALIBRATE MULTIPLIER/-10v.

(2) Adjust the X ADJ potentiometer for a -10 v, or full-scale deflection of the oscilloscope trace.

Repeat this procedure for the +10v rotary switch setting, establishing a zero on the lowermost screen marking, and adjusting for +10v deflection with the Y ADV potentiometer.

2.2.6 Calibrate D/A

This procedure establishes the proper scaling between the digital count and the analog output of the Digital-Analog Converter.

(a) On the Oscilloscope:

(1) Set vertical sensitivity to 20 mv/cm by adjusting the VERTICAL VERNIER knob for 3 cm deflection in CAL, and setting the sensitivity to 100 mv/cm.

(2) Establish a zero reference near the bottom of the reticle scale.

(b) On the PWV Computer Control Panel:

(1) Set the central rotary switch to CALIBRATE D/A.

(c) On the D/A Converter:

(1) Set the three-position lever switch to GALV. ZERO.

(2) Adjust the GALV. ZERO know for a zero reading on the oscilloscope.

(3) Set the lever switch to CALIBRATE.

(4) Adjust the CALIBRATE knob for 1.00v (5.00cm)

(5) Set the lever switch back to OPERATE.

2.2.7 Set EMD

This procedure inserts into the Analog Divider a voltage proportional to the estimated electromechanical delay (EMD) between the EKG signal and pulse expulsion.

(a) On the Oscilloscope:

(1) Set vertical sensitivity at 100 mv/cm.

(2) Establish a zero at the screen center.

(b) On the PWV Computer Control Panel:

(1) Set the rotary switch to SET EMD.

(2) Adjust the associated knob until the oscilloscope deflection in mm equals the desired EMD value in msec. A downward trace deflection of 1 cm (100 mv) is equivalent to an EMD of 10 msec (10 mv = 1 msec). The EMD can be set to zero by turning the adjust knob full counter-clockwise.

2.2.8 Set L

This procedure inserts into the Analog Divider a voltage which is proportional to the arterial length L.

(a) On the Oscilloscope:

(1) Set vertical sensitivity to 100 mv/cm.

(2) Establish a zero 2 cm above screen center.

(b) On the PWV Computer Control Panel:

(1) Set the rotary switch to SET L.

(2) Adjust the associated knob until the oscilloscope deflection in mm equals the desired length setting in cm. A 1 cm (110 mv) deflection represents an arterial length of 0.1 meters (1v = 1m). If the arterial length is greater than 1 meter, change the vertical sensitivity setting to 1 v/cm, and set a 1 cm screen deflection per 1 meter arterial length.

2.2.9 Monitor

The rotary switch is turned to the MONITOR position when the experimental run is to start. With the subject connected to the computer by means of the EKG/Pulse preamplifier cable, observe the EKG complex and the peripheral pulse waveform in turn by depressing the associated buttons on the PWV computer control panel.

Input pulses should be around 0.5 to 1 v to trigger the electronic counter. Generally no trouble will be encountered in obtaining a signal of this level from the EKG channel, but it may be necessary to reposition the pulse sensor on the subject several times before a maximal signal is observed. Oscilloscope monitoring is essential for this operation.

Triggering levels for the start and stop channels of the electronic counter are set by turning the red knobs of the LEVEL A and LEVEL B switches to DC VOLTS X 1 and then selecting the actual triggering voltage on the waveform with the lower block knobs. Once the triggering levels are properly set, the counter display will change regularly in time with the heart rate. The output PWV value can then be monitored on the oscilloscope. Establish a zero on the bottom reticle line; set vertical sensitivity to 1 v/cm. Deflection in cm represents PWV in meter/sec; that is, an upward deflection of 4.2 cm represents a PWV of 4.2 m/sec.

2.3 PWV Computer Calibration

The entire computer system can be calibrated by the following procedure:

(a) Connect an external oscillator to the "A" input of the Electronic Counter.

(b) Set the FUNCTION switch on the counter to FREQUENCY A.

(c) Set EMD equal to zero.

(d) Set standard value of L, perhaps 1 m or 0.5 m.

(e) Simultaneously adjust the frequency range of the oscillator and the TIME BASE-MULTIPLIER switch of the counter to produce a digital display which can be varied over the anticipated I range, remembering that the value of I in seconds must remain above 1/10 the value of L in meters for the Analog Divider to stay stable.

(f) For each I setting, read the output PWV value on the computer oscilloscope or on a coupled voltmeter.

(g) Compare the observed value with the theoretical value obtained by performing the calculation PWV = L/I.

Figure 8 presents system calibration curves obtained by this procedure.

3.0 Peripheral Pulse Sensor

3.1 Current Unit

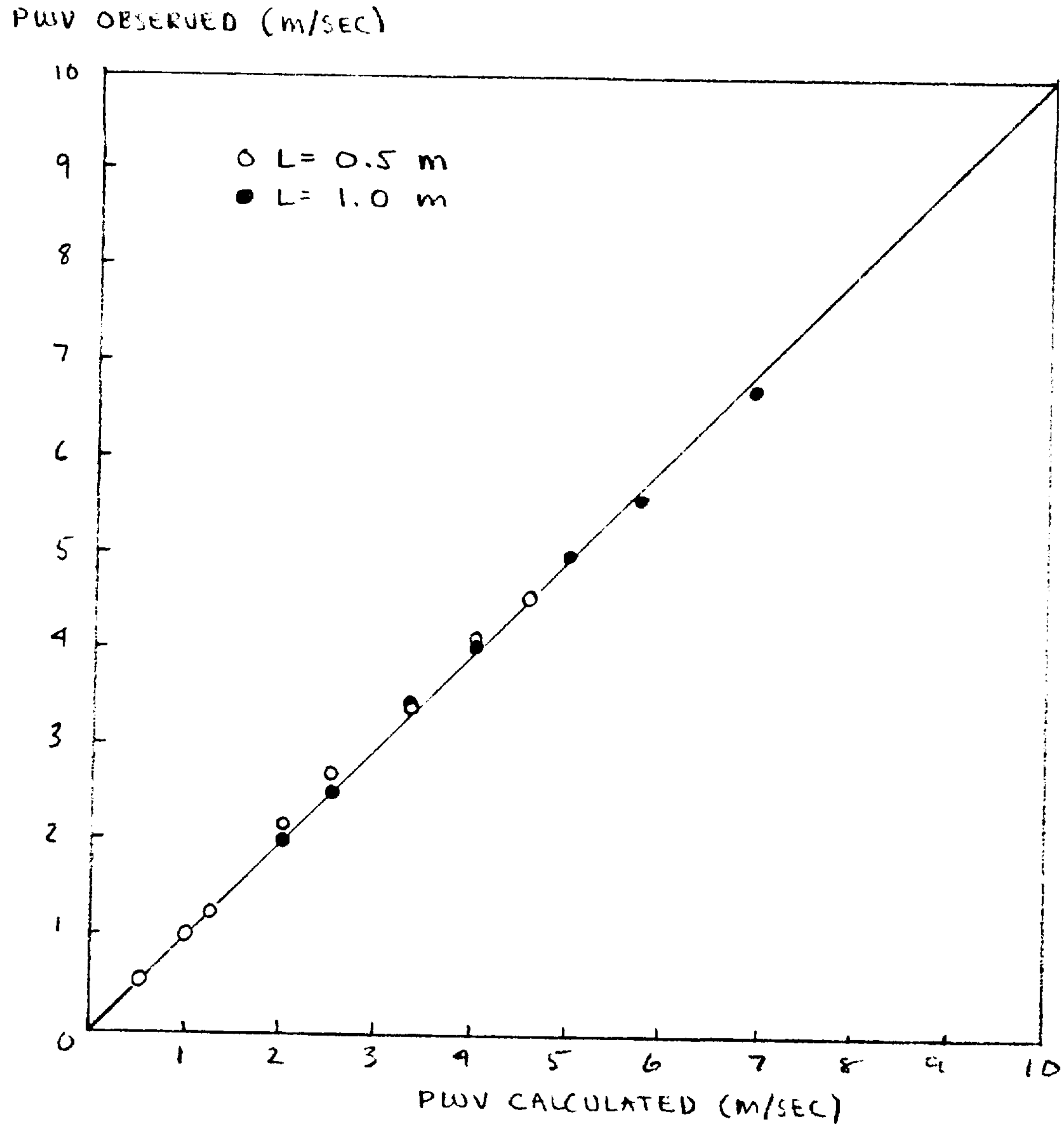
The peripheral pulse sensor supplied with the PWV Computer is a ceramic microphone manufactured specifically for biological applications by Biocom, Inc (Appendix F). It is designed to be taped or otherwise attached to the subject over a peripheral artery. When affixed in this manner on the wrist over the radial artery, it should produce about a 100-150 mv signal into the 3 megohm input resistance of the Spacelabs' pulse preamplifier. This level after amplification is adequate to trigger the Electronic Counter. A 10 megohm input impedance would increase the signal at the skin to about 300 mv.

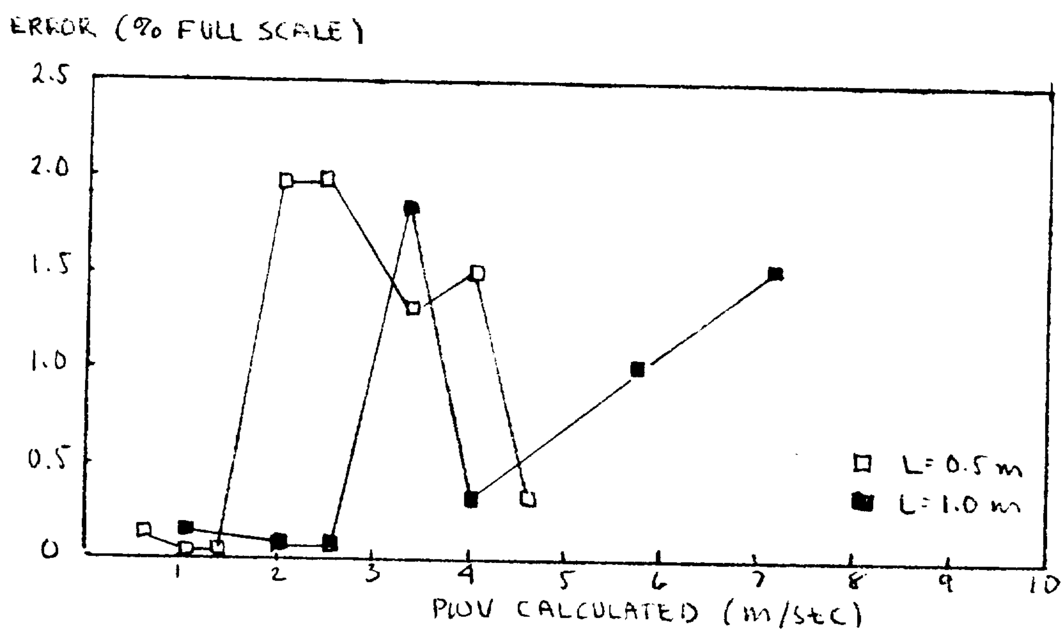
3.2 Sensor Analysis

The peripheral pulse sensor is the major trouble spot in this and all previous PWV Computer Systems. While it is generally possible to obtain a decent pulse at several peripheral sites from a quiet, cooperative subject, movement artifact usually overwhelms the pulse signal if the subject is active. The wrist transducer site, chosen because of its convenience in human experimentation, is particularly susceptible to movement noise. It has recently been thought that sites on the lower body may offer distinct advantages in this respect, as well as providing a more meaningful monitoring location during the positive G-stress encountered in many aerospace situations.

Table 1 summarizes Spacelabs' experience with peripheral pulse sensors. The pulse sensors presented are of three different types. Each type depends on the measurement of a different factor concomitant with the presence of a high-pressure, high-density mass of blood in the underlying peripheral artery. The mechanical displacement sensors depend on the fact that the pressure pulse tends to stretch the containing artery. The photoelectric sensors operate on the difference in light absorption when the pressure pulse arrives at the sensing point. The impedance plethysmograph measures the change in electrical impedance as the arterial pulse moves through a specified limb segment or limb volume.

Our requirements for the peripheral pulse transducers have not been stringent. It has been necessary only to obtain a pulse suitable for initiating a following trigger circuit. We have not been interested in maintaining great accuracy in the baseline, in the height, or in the pulse waveform. We have, however, been interested in transducing the underlying arterial pulse during subject activity, and here all the sensors evaluated have presented difficulties. These difficulties fall into two main areas: (1) movement causes the pulse sensor to shift away from the underlying artery. This either permanently reduces signal magnitude or causes transient signal artifacts. Usually the transient artifact is followed by a permanent reduction in magnitude; (2) muscle and tendon movements which are not related to the presence of the arterial pulse produce transducer signals indistinguishable from the





PWV COMPUTER CALIBRATION CURVES
(X,Y=±10.0; D/A = 1.05; MAY 23, 1969)
FIGURE 8

true peripheral pulse signals.

The transducers which depend on mechanical displacement are particularly susceptible to difficulties of the first type. In particular, those transducers which feature arterial riders are highly sensitive to displacement from the immediate vicinity of the underlying artery. Photoelectric transducers of the types previously available have also suffered this defect. Because the impedance plethysmograph can isolate an entire limb segment, it is less likely to be affected by changes in position. It was previously hoped that the impedance plethysmograph method would prove equally impervious to the muscle and tendon movement artifact which so strongly affects the mechanical displacement sensors. Unfortunately, this was not shown by experiment. The impedance plethysmograph proved exquisitely sensitive to hand movement when used to transduce the radial pulse at the wrist, producing a signal several times as large as the pulse signal itself. Several investigators, in particular a group at the Stanford Research Institute, are currently working on transducers of the mechanical displacement type which will provide a more accurate representation of the underlying pressure events. These transducers may offer some improvement in terms of movement artifact.

In our opinion, the photoelectric methods of pulse transduction appear most promising at the present time. It seems that this approach offers the highest probability of moving the signal out of the immediate vicinity of the noise. All the other methods utilize a sensing means which is virtually inseparable from the effects caused by unrelated movement. The main problem with the photoelectric sensor has been maintaining orientation over the underlying artery. This problem has been accentuated by the necessity for keeping the total light output utilized small, so as to minimize the production of heat at the skin.

Spacelabs has suggested and is currently investigating several unique approaches to improve photoelectric sensors. These include the utilization of multiple sensor elements (possibly fiber optic bundles) to introduce redundancy into the transducer, making it less sensitive to small shifts over the artery. It is not known whether such improvements would be equally beneficial in primate experimentation. Seemingly, loose skin would accentuate the problem of transducer shift.

There are several other techniques which might be used with any sensor to improve signal-to-noise ratio in the face of subject activity. The simplest of these is filtering. Although the exact location of the optimum pass-band for peripheral pulse signals is still being argued by various investigative groups, it appears as if eliminating low frequencies up to about 20 cps could somewhat decrease movement artifact. Another technique which has proven successful in similar work depends upon the production of a briefly-opened time-window during the expected arrival of the peripheral pulse. Sensor activity falling outside this interval is rejected. It is possible to base the initiation of the recording interval on the prior reception of the EKG complex. It is also possible to modify continuously the initiation time on the basis of past arrival times. Such methods have been applied in track-while-scan radar systems. Of course, the main question is whether the time-window can be made narrow enough to warrant the expense and circuit complexity necessary to generate it.

3.3 Recommendations

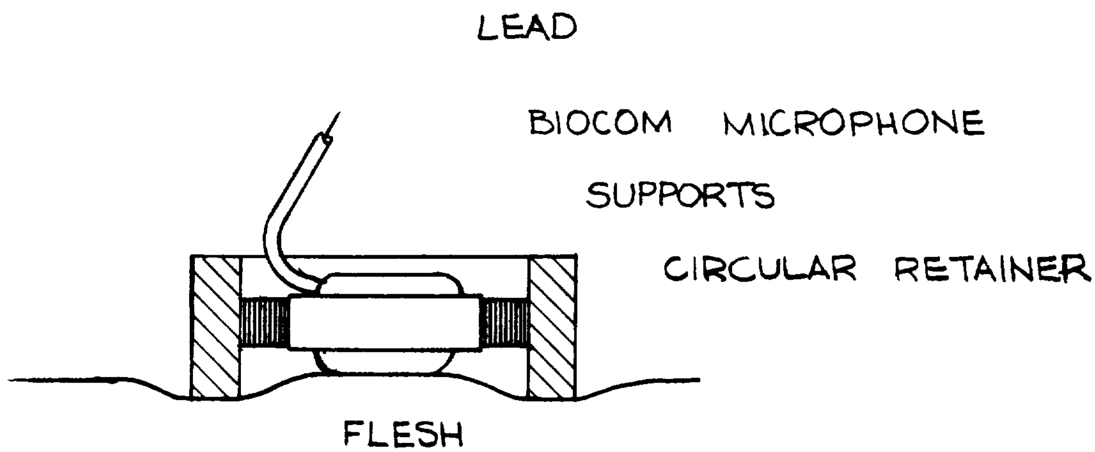
If a human subject is used:

Immobilize the wrist before applying the microphone sensor over the radial artery. Test the possibility of using the dorsalis pedis artery on the foot. If practicable, take recordings over this longer arterial distance. The foot generally moves less than the hands.

If an animal subject is used:

Make every effort to obtain a direct pulse recording through arterial catherization. It may be possible to incorporate PWV data acquisition into another circulatory experiment for which arterial puncture is already contemplated. If direct recording is necessary, immobilize the body part and strap on the microphone sensor, perhaps inserting it into a surrounding ring (as shown in Figure 9) to partially isolate it from generalized movement effects.

In either case, it would be advisable to contact the Stanford Research Institute with regard to their transducer development work, and to maintain contact with Spacelabs, Inc. to keep abreast of findings here.



A SUGGESTED APPROACH TO REDUCING INADVERTANT MOVEMENT NOISE AT THE PERIPHERAL PULSE SENSOR

FIGURE 9